Today's Topics

Wednesday, February 5, 2025 (Week 2, lecture 6) – Chapter 3.

A. Galilean Relativity

B. Newton's Laws

C. Momentum & energy

D. Gravity *by Newton*

Galilean Relativity

Definition

An **inertial frame** is a *coordinate system* moving at constant velocity.

[constant velocity = constant speed & constant direction]

→ Inertial frame = space that travels with you, e.g. car, airplane, rocket, etc …

→ Note: an accelerating/rotating system is NOT an inertial frame.

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Galilean relativity posits that in any inertial frame:

"you cannot tell that you are moving based on local measurement."

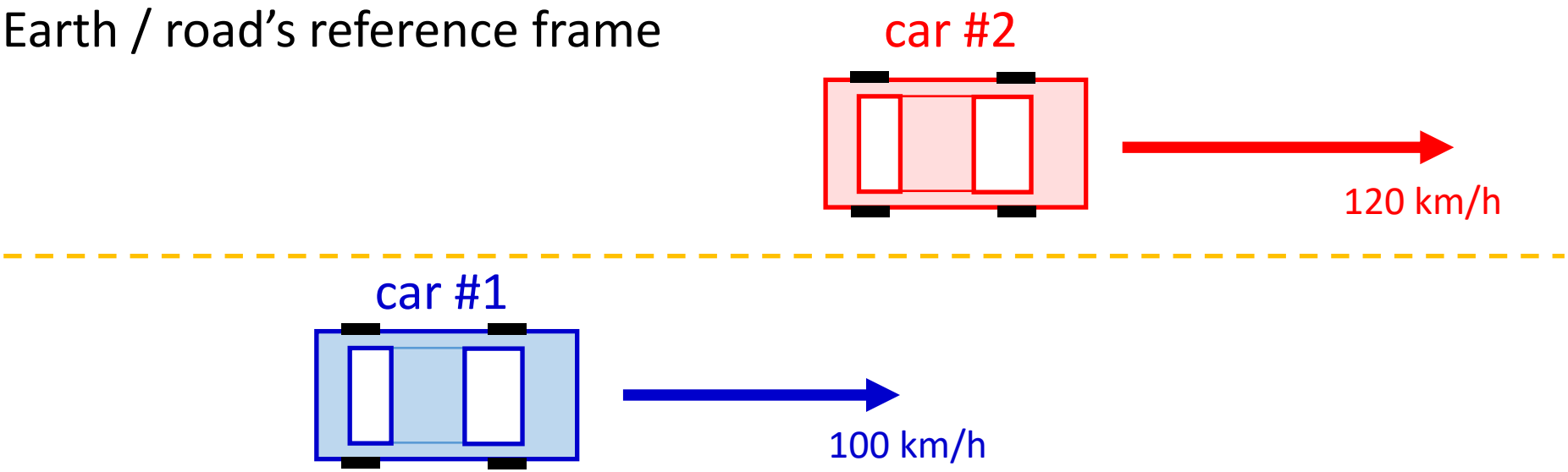
→ i.e. an inertial frame locally behaves as if it is at rest (locally).
→ **corollary:** an object in uniform motion will tend to stay in uniform motion.

Examples:

1. **Car:** You cannot tell that a car is moving (when at constant velocity) unless you look out window.
2. **Airplane:** You cannot tell an airplane is moving (when at constant velocity) unless you look out window (or hit turbulence).

Galilean Relativity Example

Earth / road's reference frame



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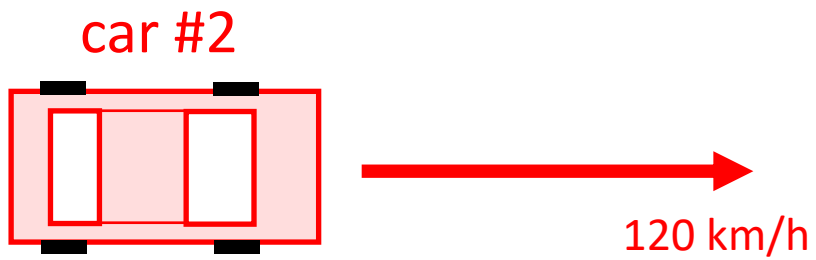
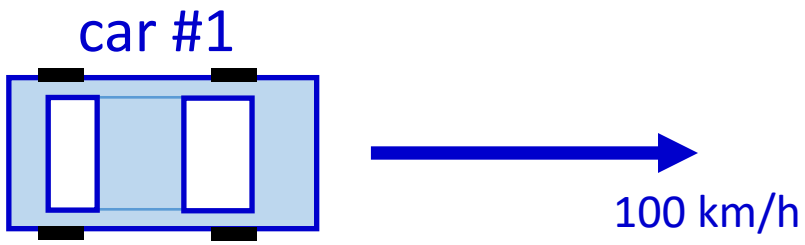
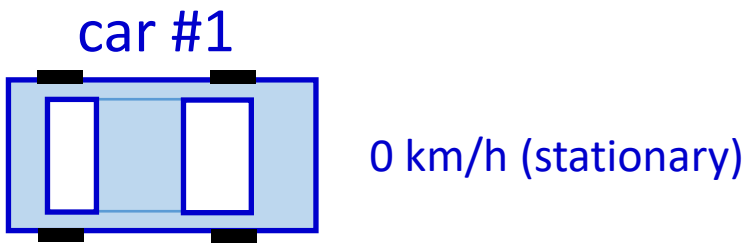


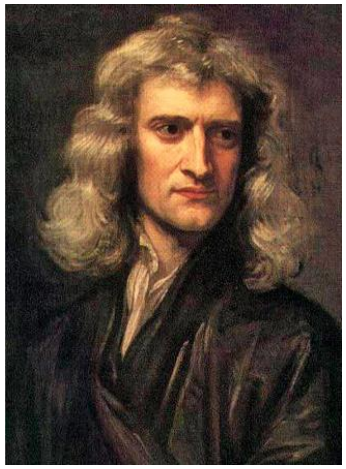


Car # 1's reference frame



PollEv Quiz: PollEv.com/sethaubin

Isaac Newton: Founder of Classical Mechanics



Newton (1689) [by G. Kneller]

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- Major contributions to **Optics & Astronomy**.

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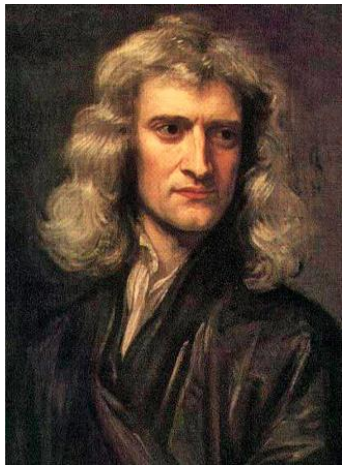

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- Law of universal gravitation.
- Newton's laws are used for ***calculating planetary & stellar motion***.

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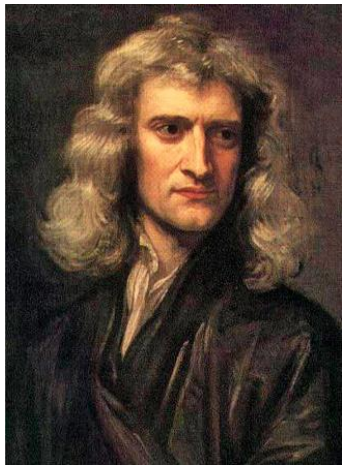

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Astronomy

- **Optics:** white light & colors, refraction.
- Invented the **reflecting telescope**.

Newton's Laws of Classical Mechanics

1st Law: An object moves at constant velocity if there is no net force acting on it.

[**fine print:** in an inertial reference frame]

2nd Law: Force = mass $\times$ acceleration.

3rd Law: For any force, there is always an equal and opposite reaction force.

Newton's 1st Law

An object moves at constant velocity if there is no net force acting on it.

[**fine print:** in an inertial reference frame]

Note: *This law is a variation on the Galilean relativity statement.*

Newton's 2nd Law

Force = Mass × Acceleration

or

$$F = ma$$

F = net force
m = mass
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Note 1: This equation is mostly useful if you know the net force applied.

Note 2: If the acceleration is zero, then the net force is zero.

Newton's 3rd Law

For any force, there is always an equal and opposite reaction force

$$F_{A\to B} = -F_{B\to A}$$

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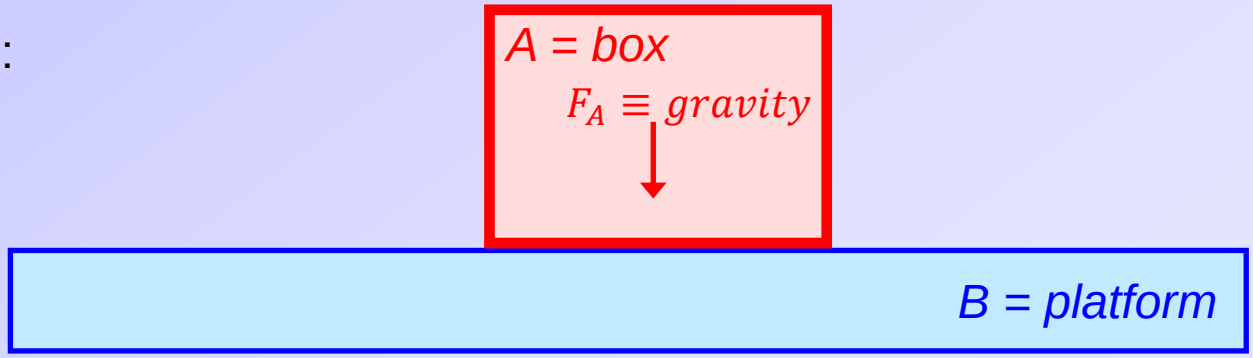

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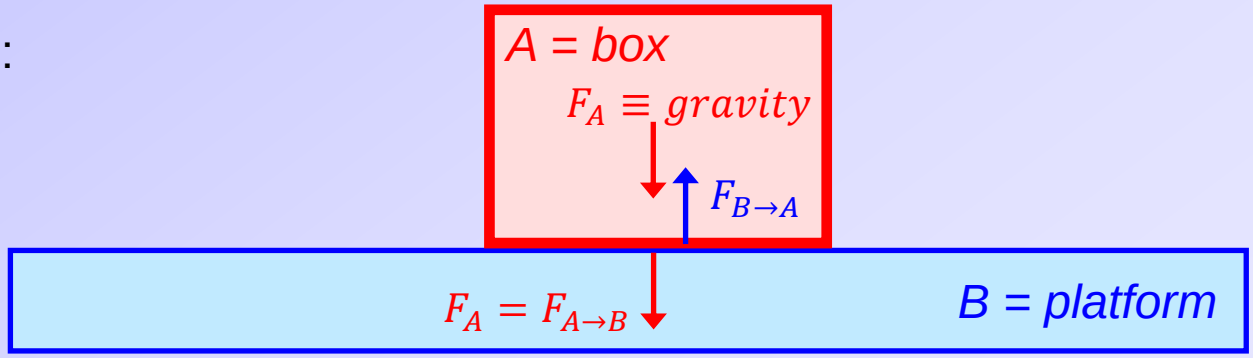

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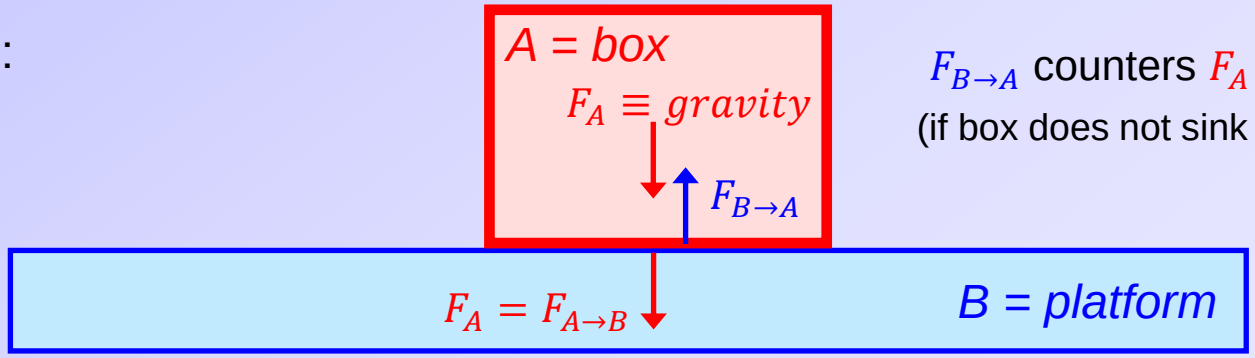

$F_{B\to A}$ counters F_A exactly.
(if box does not sink into platform)

Newton's 3rd Law: Rocket Thrust

A rocket accelerates by pushing on its exhaust.

A rocket does NOT push on the air to accelerate.

A rocket does NOT push on its platform to accelerate.

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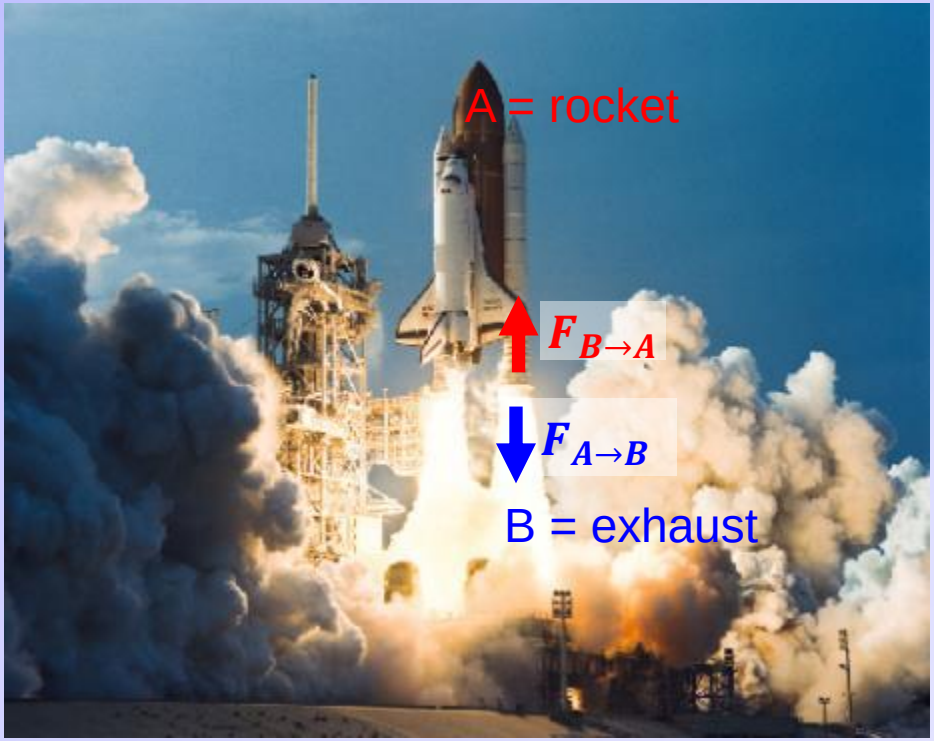

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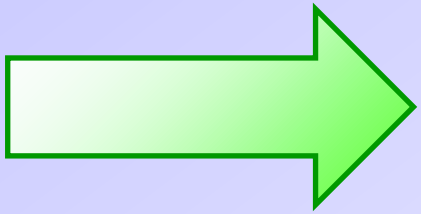

- Conservation of ***Momentum***.
- Conservation of ***Energy***.

Conservation of Momentum

momentum = mass $\times$ velocity

total momentum
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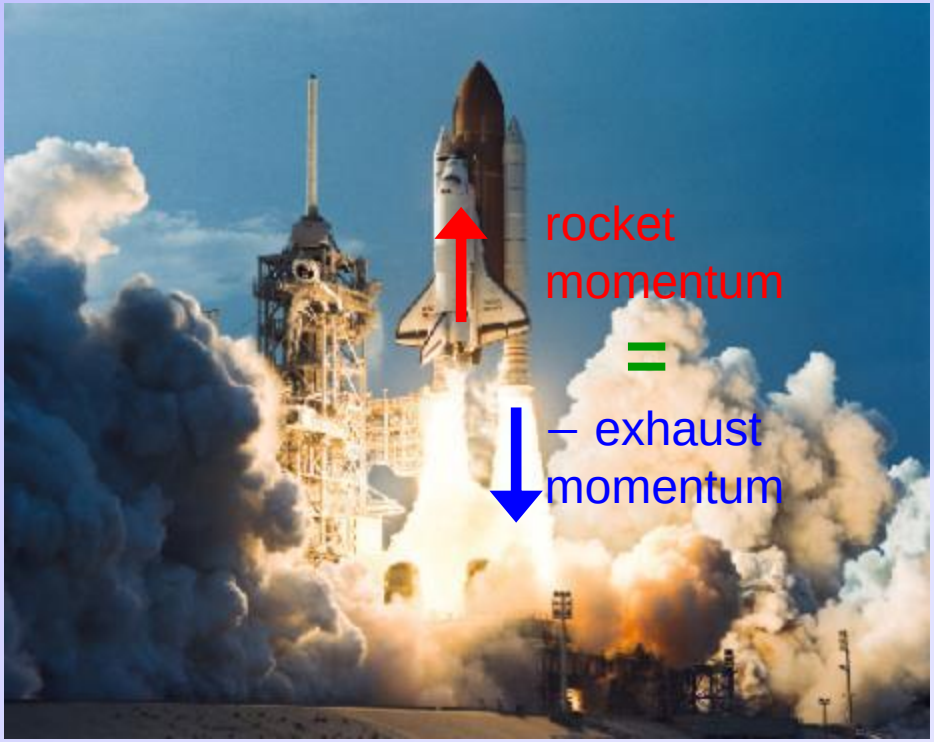
Conservation Law
The total momentum of a closed system never changes.

no external objects enter
no external forces

Momentum Conservation: Rocket Thrust

$$\text{Momentum}_{\text{rocket}} + \text{Momentum}_{\text{exhaust}} = 0$$



Conservation of Energy

Kinetic Energy $= E_k = \frac{1}{2}mv^2$

m = mass
v = speed

Potential Energy = “stored” energy

example: gravitational potential energy

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Newton's law of universal gravitation

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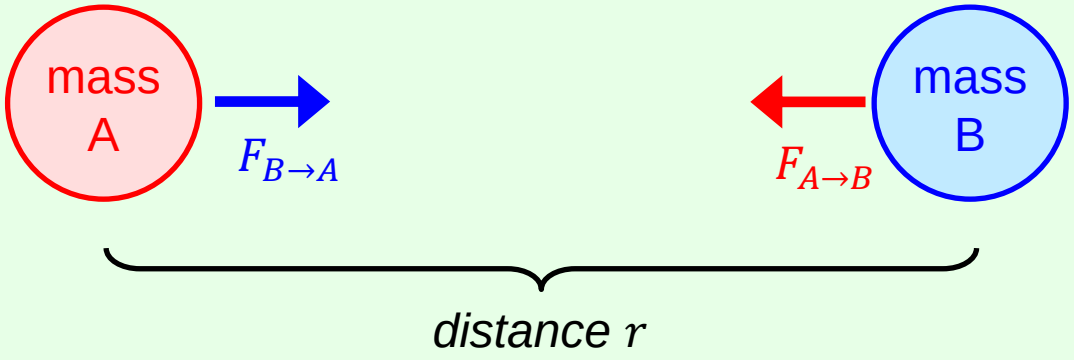

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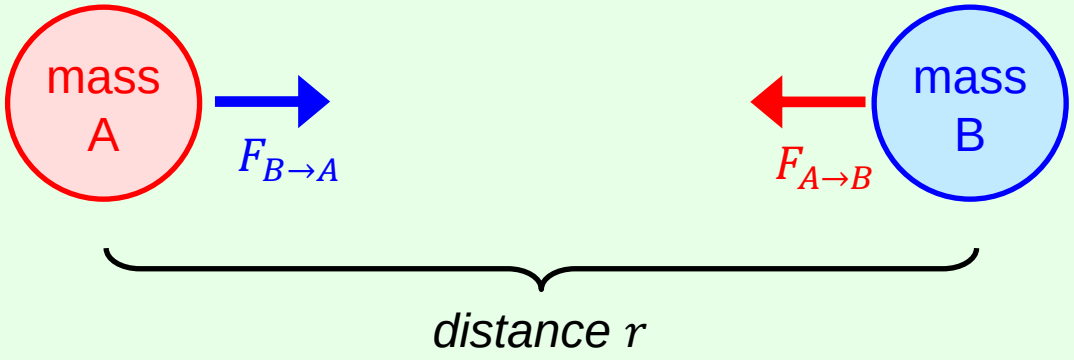


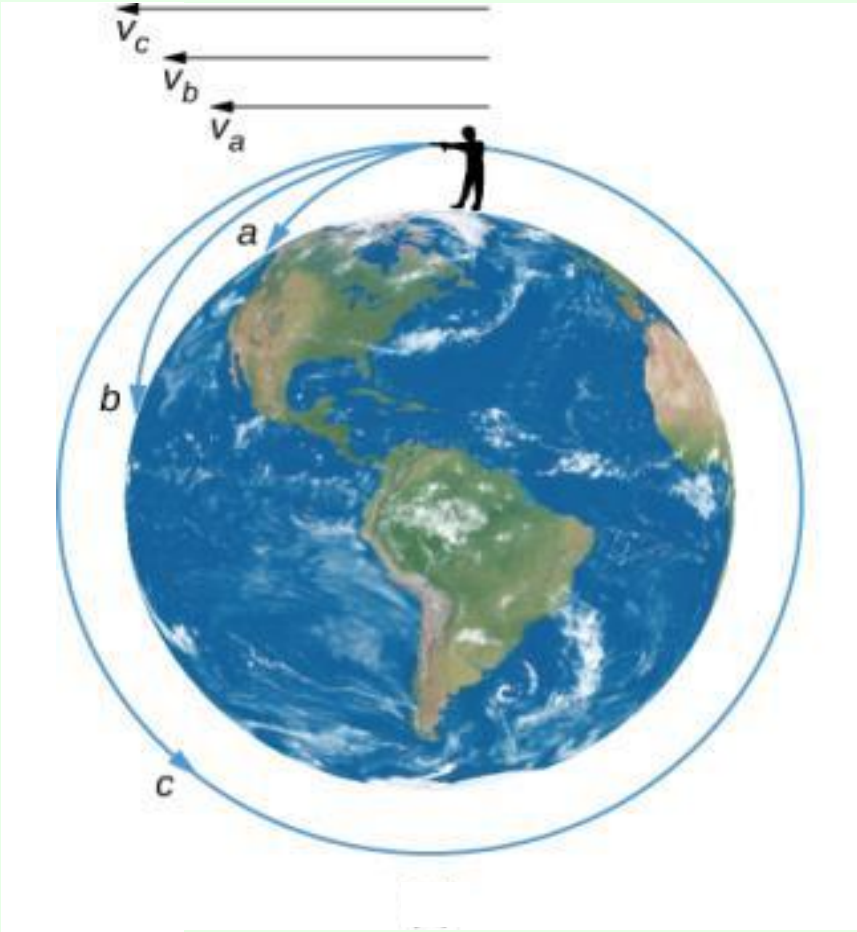
Properties

- Falls off as $1/r^2$.
- Proportional to M_A.
- Proportional to M_B.
- G = Newton's constant $= 6.67430(15) \times 10^{-11}$ $m^3/Kg \cdot s^2$

Why do all objects fall at the same rate?

(to be covered in problem session)

Orbiting is free falling while missing Earth



[OpenStax: Astronomy]

Paths a & b: Initial speeds are weak enough that Earth's gravity pulls the projectile back to the surface.

Path c: Initial speed is strong enough that Earth's gravity never pulls the projectile back to the surface.

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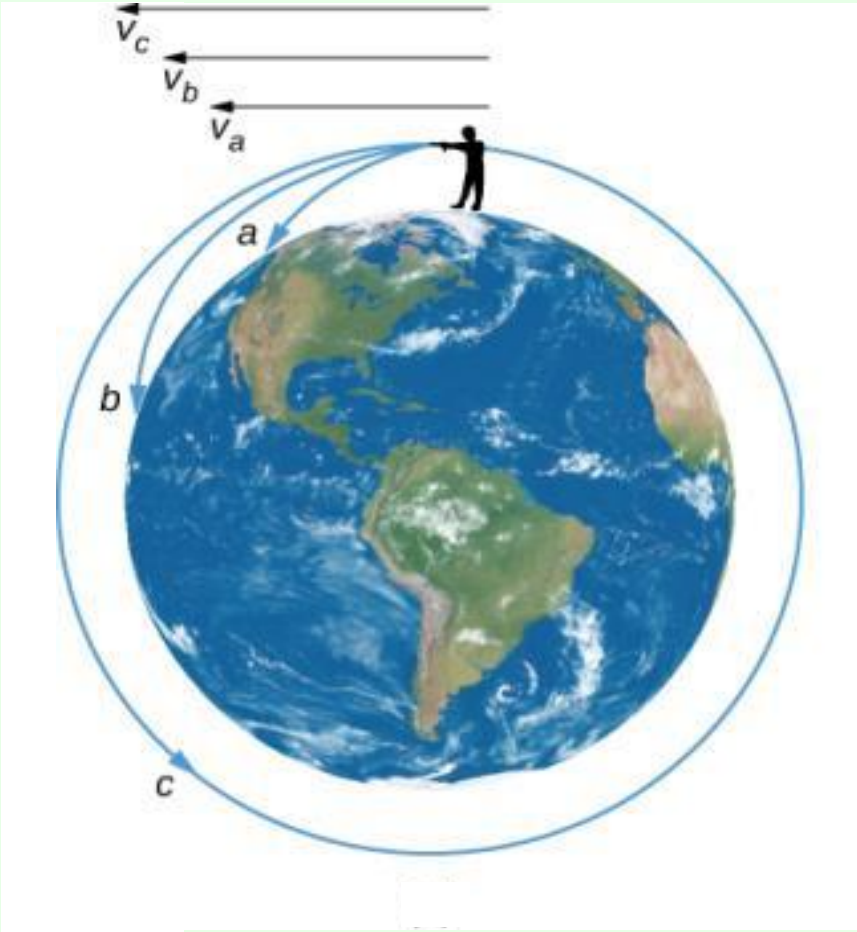

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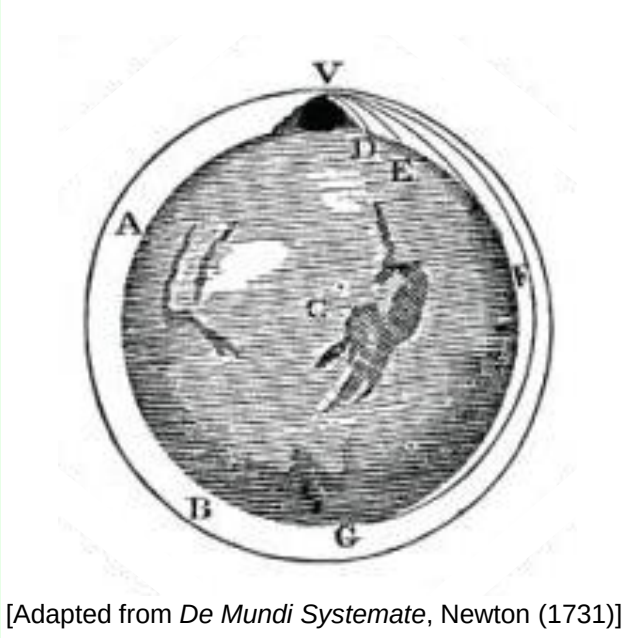

[Adapted from *De Mundi Systemate*, Newton (1731)]

orbiting

“The knack of flying is learning how to throw yourself at the ground and miss”

- Hitchhikers Guide to the Galaxy

Weightless in Orbit

Clockwise from top left: Tracy Caldwell Dyson (NASA), Naoko Yamzaki (JAXA), Dorothy Metcalf-Lindenburger (NASA), and Stephanie Wilson (NASA). (credit: NASA)

Astronauts in Free Fall: While in space, astronauts are falling freely, so they experience “weightlessness.”